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WATER-POWER
IN
THE BRITISH EMPIRE

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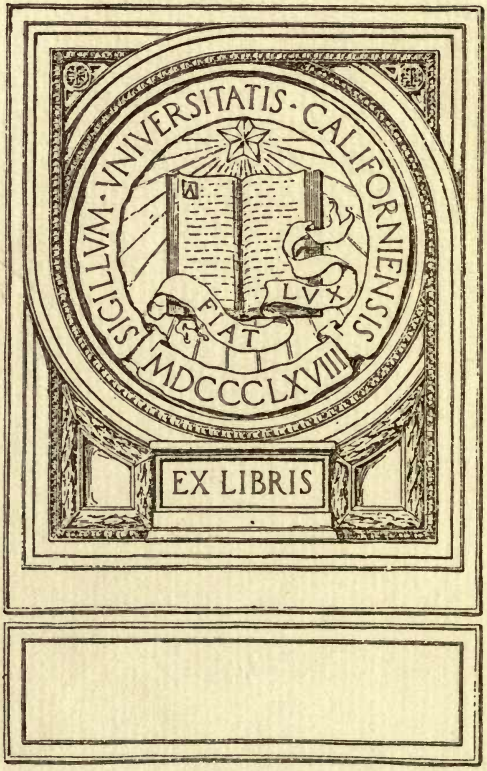
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WATER-POWER IN THE BRITISH EMPIRE

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THE REPORTS OF THE WATER-POWER COMMITTEE OF THE CONJOINT BOARD OF SCIENTIFIC SOCIETIES

SIR DUGALD CLERK, K.B.E., F.R.S. (CHAIRMAN)
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PREFACE

In the first census of production for the year 1907, the total power of industrial engines in use in Great Britain and Ireland is given as 10,578,475 h.p., and the steam-engine power of road rollers and road locomotives owned by public authorities amounted to 167,192 h.p. Of the industrial engines, steam-reciprocating engines were rated at 9,118,818 h.p.; steam turbines, 530,892; internal-combustion engines, gas, oil, etc. 680,177; and water-power, 177,907 h.p. The persons employed in the factories using this large power numbered nearly 10½ millions; so that, roughly, the power available for the industries of Britain was nearly 1 h.p. per person employed. To support the 46 millions of people now living in the United Kingdom thus requires a continuous enormous expenditure of power, and a very large consumption of fuel.

The present position of the coal question is supposed by some to be very temporary, and it is hoped that shortly we may resume our former fortunate state when coal was plentiful and motive power and heating very economical from the money viewpoint.

The coal position of the world, however, must deteriorate from decade to decade, and it might be of advantage to consider our position in a coalless and oilless world. The position of Great Britain and the Empire is, however, sufficient for us. The combined report of the Water-Power Committee of the Conjoint Board of Scientific Societies considers Great Britain and the Empire in relation to the main alternative to fuel—that is, water-power.

The world may be considered as a huge solar engine, in which the waters of the seas are evaporated by the heat

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absorbed, and much of the vapour carried to high levels, at which it is deposited as water, and flows down to the sea. By this process we get a complete cycle of operations, including evaporation of water into steam, condensation of the steam into water, evaporation again, and so on. In falling from the high level to the low level of the sea, power can be obtained from this water. Hydraulic power, in fact, is a form of sun power, and will continue in existence long after all the coal and oil in the world have been exhausted. Coal and oil have also been produced by the action of the great solar engine, and they contain a portion of the energy of radiation of past ages, stored up in the growing wood and leaves of plants, accumulations which are now being rapidly drawn upon by mankind. Coal and oil are thus the result of past radiant energy, while wind and water power are due to present radiant energy. In one case the store in the earth is being used up and cannot be replaced; in the other case, so long as the solar system lasts, power exists also.

Undoubtedly, as time goes on, hydraulic power must become of increasing importance. We must look to water-power as a substitute for coal-power in its many forms of reciprocating steam engines, steam turbines, and coal gas, blast-furnace gas and producer-gas engines, in an increasing measure as coal becomes scarcer and therefore more expensive.

It is obviously of importance for us to consider the position of hydraulic power in this country and throughout the Empire. With this object a Committee was formed in November, 1917, by the Conjoint Board of Scientific Societies to collect data and report as to the position of the British Empire. This Committee was followed by a Board of Trade Committee on the water-power of the United Kingdom.

Both Committees have now reported, and, accordingly, as Chairman of the British Empire Water-Power Committee and a member of the Board of Trade Water-Power Resources

Committee of the United Kingdom, I am now able to give an outline of the present position.

Taking the United Kingdom first, there appears to be a total of 1,350,000 h.p. available continuously throughout the twenty-four hours, and if any great tidal scheme be included, such as that of the Severn recently widely discussed, another 400,000 continuous h.p. must be added, giving a total of 1,750,000 continuous h.p. divided as follows:

England and Wales	450,000 h.p. 24 hours.
Scotland	400,000 „ „ „
Ireland	500,000 „ „ „
Tidal schemes (Severn) ..	400,000 „ „ „
	1,750,000 h.p. continuous.

This total could be obtained if required, but at a cost higher than appears necessary at present. In Scotland, however, an additional power of 183,000 h.p. continuous is immediately feasible, as is shown by the expert examination of nine schemes having average outputs ranging from 7,000 to 40,000 continuous twenty-four hours h.p. These schemes could be developed at a cost appreciably less than from coal-fired stations built and operated under existing conditions. In England and Wales the cost of development is greater, but a large proportion of the total is quite commercial. In Ireland the position appears to be highly favourable, and it is considered that the whole industrial power acquired for that country could be supplied seven times over. Ireland could be run for motive power and railways by hydraulic power alone, and coal and other fuel consumption could be entirely dispensed with for power purposes. The 10 million h.p. of heat engines could not be entirely supplied by water-power, but very substantial fuel savings could be made by a much extended use of water.

In comparing water and heat-engine power it is to be remembered that continuous water-power applied twenty-four

hours per day gives three times the energy of heat-engine power at eight hours per day, so that if storage arrangements be successfully applied, 1 million horse continuous hydraulic power is equivalent to 3 million steam or other heat-engine power which is available at the estimated fuel cost for eight hours per day only.

Seventy-five million h.p. are used for factories and general industrial and municipal activities throughout the world; a rough approximation of the most probable distribution would appear to be, in millions of horse-power: United Kingdom 13, Continental Europe 24, United States 29, British Dominions and Dependencies 6, and Asia and South America 3.

Of this 75 million industrial h.p. 15 to 16 million is at present developed by water-power. This is distributed in various regions as follows:

	United Kingdom.	*Continental Europe.*	*United States.*	*Colonies.*
Millions of h.p... ..	0·08	6·5	7·0	2·0
Percentage of total industrial h.p.	0·6	27·0	24·0	33·0

It is interesting to note the small proportion of our total motive power which was developed from our water-power resources a few years back. The position is now improved and the use of water-power is increasing with us. It is striking, however, to find that Continental Europe uses water for 27 per cent. of her total motive power, and the United States 24 per cent., while the United Kingdom only used 0·6 per cent. Our Colonies, however, use water at present for 33 per cent. of their total industrial power. Canada has been most active and successful in utilising her hydraulic power, and the hydro-electric practice of the Canadian engineers provides valuable information for the United Kingdom and the other parts of the British Empire.

In view of the very large water-power resources of the United States and the relatively large hydraulic powers possible in Austria, Hungary, France, Norway, Spain, Sweden, and Italy, amounting approximately to 59 million h.p., the small British total appears insignificant. The case is very different when we consider the British Empire. Canada has nearly 27 million hydraulic h.p. available, and when India, New Guinea, and New Zealand are added we attain a potential power of the order of 40 millions. When we add to this the water resources of East, South, and Central Africa, Egypt, Ceylon, Tasmania, Australia, British Guiana, Burma, the Malay States, and our own Islands, the aggregate hydraulic power of the Empire approaches 70 million continuous h.p —a truly remarkable power to be used in the present to a small extent and in the future to a very large extent as coal resources become reduced. This huge source of power has been neglected by us in the past for many reasons, principally because we were fortunate in Great Britain in possessing abundance of coal easily raised to the surface and adjoining large iron-ore deposits.

One of our pressing duties as engineers consists in devoting ourselves to the most serious consideration of applying all possible water-power to supplement the work of coal, and so reduce consumption or increase the utility of our most important asset.

Suggestions are made in the combined report of the Conjoint Board as to co-operation throughout the Empire to utilise the great stores of water-power which we possess, and I would recommend all engineers to study this report, the Board of Trade Committee Report, and the able British Association Address given by Professor Gibson in 1921.

DUGALD CLERK.

NOTE.—1 k.w. is the equivalent of 1·34 e.h.p.

1 e.h.p. is the equivalent of approximately 1·33 water horse-power.

WATER-POWER IN THE BRITISH EMPIRE

INTRODUCTION

THE Water-Power Committee of the Conjoint Board of Scientific Societies was appointed in 1917, its terms of reference being "to report on what is at present being done to ascertain the amount and distribution of water-power in the British Empire."

With this in view, the Committee has endeavoured to collect all available relevant information. It presented a first report in July, 1918; a second report in March, 1919; and a third and final report in January, 1921.

Considerable public interest has been evinced in these various reports, and the present volume is an endeavour to incorporate their salient features in a form readily available to anyone interested in this subject.

In the light of more recent information, it has been found necessary to modify some of the figures of the earlier reports. In such cases the modified figures are now given.

In its preliminary report the Committee thought it desirable to exceed somewhat its terms of reference, and, in view of the great importance of the matter, to devote some little space to the general question of water-power and its utilisation.

NEEDS OF THE EMPIRE.

To enable the Empire to recover, with any degree of rapidity, from the financial burden imposed by the War, it will be necessary to develop, in a much greater degree than heretofore, its latent resources. The wealth embodied in its mineral resources, its wheat areas, its forests, and the hundred products of its tropical dependencies, is almost incalculably great. But it must be realised that without an ample supply of cheap energy much of this wealth must always remain latent.

Energy is required to enable the mineral ores to be won and refined. It is required for the adequate fertilisation of the

land, as well as for the harvesting and transportation of its crops and products; and any scheme for the extensive development of the Empire's resources as a whole must depend upon the preliminary development of its energy supplies.

The available sources of energy are, for practical purposes, few in number. They comprise our fossil fuels, our oil-fields and oil shale deposits, and our water-powers.

In considering the relative value and importance of these sources of energy, it is to be remembered that while the solid and liquid fuels are convenient to handle, can be easily and cheaply transported to any convenient locality, and in many cases form, at present, the most convenient and cheap source of power, yet their supplies are strictly limited, and their ultimate depletion is assured. Fortunately, public opinion is now awakening in some degree to the necessity for their conservation. Still, long before the supplies are actually exhausted, increasing scarcity is bound to put up their cost to a level much higher than that now obtaining.

In view of this, the utilisation, to the utmost possible degree, of the water-powers of the Empire becomes of paramount importance. Excepting the comparatively small and inconvenient supply of energy obtainable from vegetable growth, either by direct combustion or through the medium of alcohol, these at present provide our only practical perennial source of energy.

The economic development of many of our tropical dependencies, whose latent wealth is practically untapped, is directly interconnected with the development of their water-power resources. Not only would an abundant supply of cheap power enable railroads to be operated, irrigation schemes to be developed, and mineral deposits to be tapped and worked, but it would go far to solve the labour problem, which promises to be one of some difficulty in the near future.

The World's Present Power Demand.

It is impossible to estimate with any pretensions to accuracy the power now being used in the various countries of the world. Independent estimates,* based on such data as are avail-

* "The World's Supplies of Fuel and Motive Power." Hawksley Lecture. Inst. Mech. Engineers, 1915. Sir Dugald Clerk.
"Natural Sources of Energy." A. H. Gibson. Cambridge University Press, 1914.

able, tend, however, to show that it is of the order of 120 million h.p. made up approximately as follows:

World's factories, including electric lighting and street railways ..	75	million h.p.
World's railways	21	„ „
World's shipping	24	„ „
Total ..	120	„ „

This includes all steam, gas, and water power.

Of the 75 million h.p. used for factories and general industrial and municipal activities, a rough approximation of the most probable distribution would appear to be—

	United Kingdom.	*Continental Europe.*	*United States.*	*British Dominions and Dependencies.*	*Asia and South America.*
Millions of h.p.	13	24	29	6	3

A recent estimate outlines the hydraulic situation of the various countries as follows:

Country.	*Area (Sq. Miles).*	*Population (Latest Available Figures, Pre-War Boundaries).*	*B.H.P. Available.*	*B.H.P. Developed.*	*Per Cent. Utilised.*	*H.P. per Sq. Mile of Area Available.*	*H.P. per Sq. Mile of Area Developed.*
United States	3,026,600[1]	92,019,900	28,100,000	7,500,000	26·7	9·3	2·48
Canada ..	2,000,000	8,033,500	22,900,000	3,385,000	14·8	11·45	1·69
Austria-Hungary..	241,330	49,418,600	6,460,000	570,000	8·8	26·8	2·37
France ..	207,100	39,601,500	5,587,000	1,500,000	26·9	27·0	7·24
Norway ..	124,130	2,302,700	6,500,000	1,250,000	19·2	52·9	10·1
Spain ..	194,700	18,618,100	5,000,000	540,000	10·8	25·7	2·77
Sweden ..	172,900	5,521,900	5,500,000	1,100,000	20·0	31·8	6·36
Italy ..	91,280	28,601,600	4,000,000	1,250,000	31·3	43·8	13·7
Switzerland	15,976	3,742,000	3,000,000	650,000	21·7	188·5	40·7
Germany ..	208,800	64,903,400	1,425,000	750,100	52·5	6·8	3·59
Great Britain	88,980	40,831,400	900,000	200,000	22·2	10·2	2·25

[1] Excluding Alaska (area about half a million square miles).

Canada.—2,000,000 square miles is taken as the area treated in the Conservation Commission's estimate of available water-power, and the area which we may expect to see fairly thickly settled during the next few decades. The area of the whole Dominion is 3,729,750 square miles.

These developed powers include schemes in course of construction, and refer to the ultimate installed turbine capacity.

The Empire's Water-Power Possibilities.

The question as to the amount of potential water-power in the Dominions and Dependencies of the Empire is dealt with in more detail in the following pages.* So great is the lack of reliable data, however, in reference to all but one or two of the Colonies, that any estimate of the total power must be looked upon as highly speculative. The main powers are to be looked for in Canada, India, New Guinea, and New Zealand, and it is fairly certain that in these countries alone there is a potential water horse-power of the order of 40 millions. When to this are added the resources of East, South, and Central Africa, Egypt, Ceylon, Tasmania, Australia, British Guiana, Burma, the Malay States, and our own Islands, it appears that in the aggregate the hydraulic resources of the Empire are extremely large, and that they are as yet barely tapped.

Reason for Neglect in the Past.—There have been many good reasons for their comparative neglect in the past. The general abundance of coal in proximity to centres of industry; the necessity for a heavy initial outlay to bring most of the larger powers into bearing; the lack of co-ordination between possible producers, users, and financiers of power; the lack of markets for the energy which would be made available; and the remoteness of most of the powers from present centres of activity, have all contributed. Moreover, the highly efficient combination of the hydraulic turbine and the electric generator, capable of handling large powers, is of comparatively recent development.

Recent Development.—The developments in engineering science in the past decade, and more particularly the developments in electro-chemical, electro-physical, and electro-

* Wherever hereafter in this report the term "horse-power" is used, it is to be taken as meaning continuous twenty-four-hour power unless otherwise stated.

metallurgical processes, and in the possibility of high-voltage electrical transmission, have removed some of these reasons. Transmission lines exceeding 200 miles in length are in existence to-day, and only financial considerations now set a limit to their possible length. Any distance is feasible electrically and mechanically.

Electro-metallurgy and electro-chemistry have rendered it possible to handle materials not workable by any other means, have made available new materials, and have greatly cheapened the production of many important materials of wide use. Aluminium, calcium carbide, chromium, cyanide, silicon, carborundum are products rendered commercially possible only by electrical processes, while alkalies, hypochlorite, phosphorus, magnesium, and sodium nitrate are produced most economically by such processes. Great developments have recently taken place in the production of electrolytic copper and zinc and in processes of the electric smelting and refining of metallic ores.

All these processes demand relatively large amounts of energy. The world's production of calcium carbide, for example, was 340,000 tons in 1913, requiring 400,000 continuous e.h.p. for its production, while the energy used at the end of 1915 for electric furnaces in the United States alone was approximately 300,000 e.h.p.

In the utilisation of atmospheric nitrogen for the production of nitric acid and the manufacture of nitrates, great developments have taken place during the last decade, and in Norway alone over 400,000 e.h.p. is now absorbed in its production. The world's annual consumption of nitrogen in its various combinations is about 750,000 tons, representing a value of about £50,000,000, and this demand is increasing yearly. Four-fifths of this supply has been produced hitherto from natural nitrate deposits, but in view of the rapid depletion of these deposits, and of the diminution in the fertility of most of the great wheat and cotton growing areas of the world, the production of artificial fertilisers by one or other system of nitrogen fixation must, in the near future, become a question of national importance.

At the present time the world's consumption of fertilisers amounts to close upon 6,000,000 tons per annum, and this will probably be doubled within the next twenty years.

To-day the efficiency of the electrical production is low, amounting in the case of calcium nitrate to about three-quarters of a ton per e.h.p. year. By adopting the cyanamide process the consumption of energy may be cut down to about one-fourth, but even in this case the production of the equivalent of 12,000,000 tons of fertilisers per annum would require 4,000,000 continuous e.h.p.

It is estimated that the 200,000,000 acres of arable land in Canada alone may ultimately require some 10,000,000 tons of nitrates per annum to maintain their fertility, and this in itself would necessitate the absorption of an appreciable portion of the whole hydraulic energy of the Dominion.

When to these demands are added those of India, Australia, and Africa, it is evident that the fertiliser demand of the Empire will in itself call for an enormous supply of energy.

Apart from these requirements, which are admittedly for the future, electric power has a wide and practically unlimited field as a motive power conveniently and economically adaptable to any class of service. In the heating and welding of metals as a part of the process of manufacture, electricity, by its control, speed, and concentration of distribution, has many advantages over coal or gas.

Great developments in the electrification of trunk lines have taken place during recent years. In the United States, 440 miles of the Chicago, Milwaukee, and St. Paul Railway, comprising 590 miles of single track, have already been electrified, while contracts for the electrification of other sections of the line have been let. On the completion of this work the total length of electrified track on the system will be about 860 miles. Electric power for operation is obtained from hydro-electric stations.

In France much of the line of the Compagnie du Midi in the region of the Pyrenees has already been electrified with the aid of water-power, and the electrification of trunk lines in many other countries is at present under consideration. It is apparent that the electrification of railways will open up a very large field for the utilisation of water-power where this is available.

Necessity for State Control.

The considerations already outlined would indicate that the conservation and utilisation of the water-power resources of

the Empire is likely to be one of the most important problems in our political economy.

The solution of this problem involves many complex questions of law, of administration, and of engineering and economic investigation, if the public interest is to be best served by the development.

In view of the immensity of the interests involved, it is urged that nothing short of statutory control of these developments is desirable. The exact method of control is not for the Committee to suggest. So far as is possible private enterprise should be encouraged, but under conditions which would prevent the perpetual rights being lost to the community.

In this connection it is worthy of note that Canada and New Zealand have State control over the majority of their water-powers, and that in all provinces in India there are Canal Acts which expressly lay down that Government is entitled to use and control for public purposes the water of all rivers and streams flowing in natural channels. In the case of Australia, each State has enacted lengthy legislation in relation to water conservation, but no special clauses appear in respect of developable water-power. It is also suggestive that the Administration in Washington is at present taking steps to control the development of water-powers on all public lands and navigable streams in the United States; that, in spite of the revolution in Russia, the Provisional Government has recently appointed a Water-Power Committee, with absolute control over the development of all water-power schemes in the Empire exceeding 300 h.p.; and that the Austrian Government has, quite recently, introduced a Bill for the promotion of hydro-electrical development, giving the State the right to acquire any undertaking after the expiration of twenty-five years, and at the end of any subsequent period of five years.

It should be recognised, however, that while it is essential that the State should have the right of ultimate purchase, the period of such purchase should not be unduly short or the terms too onerous. It will be remembered that such legislation had the effect of severely handicapping the electric power and lighting industry in the early days of its development.

Necessity for Preliminary Investigations.

In spite of the great importance of water-powers, many of the potential powers in existence must of necessity prove economically useless, either on account of their great distance from centres of industry, the lack of transport facilities, or from the fact that the storage necessary to give a continuous or fairly continuous supply would be too costly. Of many potential powers it can be said without further investigation that for the present this is, and for a long period to come will be, the case. Of others the reverse is true, and it is evident that the scheme will amply repay development. But in the majority of cases the extent to which a scheme is capable of economic development can only be determined after a careful examination of the catchment area and of the site of the proposed works; after a careful and prolonged investigation of the rainfall and run-off records; and, especially in an undeveloped country, after an investigation of the mineral and forestal or agricultural possibilities of the surrounding region.

It has usually been understood that the usefulness of a water-supply depends on the possibility of maintaining its uniformity over the whole period of the year, and that the maximum useful power is strictly limited by the minimum power which, by the aid of any suggested storage system, will be available towards the end of the longest probable period of drought.

Where the power is utilised for the supply of some industrial centre this is undoubtedly true, but if the idea were to be generally adopted it would cut out an enormous aggregate of potential power, more particularly in tropical and semi-tropical countries. The possibility of utilising flood supplies for seasonal operations in connection with mining, agriculture, and forestry, or for the production of nitrates in such cases, would appear to be worthy of close consideration.

In any case, the possibilities of a given scheme can only be determined after a prolonged hydrographical and meteorological investigation of the site and surroundings. To be of real value such an investigation should extend over a long series of years. Rainfall records, though forming the basis of any such investigation, are only of partial assistance in dealing with water-power questions. The actual run-off from the catchment area is the all-important factor, and the ratio of run-

off to rainfall varies with the physical characteristics of the area, the vegetation, and the climate, so that rainfall gaugings cannot be substituted for the more laborious and costly collection of continuous records of river levels, combined with frequent gaugings of flow. It must be emphasised that each scheme of development requires independent and extended investigations to determine completely the local conditions governing the flow from the area intended to be utilised.

The United States Government, which has given close attention to this matter for the past thirty years, lays repeated and urgent stress on this point. It states,* for instance:

"It is essential that records of stream-flow should be kept, during a period of years, long enough to determine, within reasonable limits, the range of flow from maximum to minimum. The length of such a period manifestly varies for different streams. Experience has shown that the records should be kept for from five to twenty years."

The Dominion Water-Power Branch, Canada, states:†

"It is essential that the records, in order that they may properly cover all possible range in stage of the rivers investigated, should extend over a considerable term of years. On some streams this term should be from five to ten years, while in other cases it should extend over a much longer period, say from ten to twenty years. . . . The standpoint taken by the U.S. Geological Survey is that, owing to the constantly changing flow of streams, data of reasonable accuracy showing the distribution of flow over several consecutive years are of more importance than very accurate measurements covering short periods of time."

It should be remembered also that these investigations are of value, not only in relation to water-power, but also to navigation, irrigation, reclamation, flooding, and domestic use. In this connection the United States Commission of Conservation‡ have made an estimate of the benefits that would accrue in that country from improvements to water-

* Water-Supply Paper, No. 336. Washington, U.S.A.

† Water Resources, Paper No. 4. Dominion Water-Power Branch, Ottawa.

‡ Report of the National Conservation Commission, Washington, 1909. Vol. i., p. 48.

ways for the purpose of navigation and from the utilisation of only such water-powers as would thereby be created.

The report states:

"It has been roughly estimated that the inland waterways of the country could be improved in ten years at a cost of £10,000,000 annually in such a manner as to improve inter-State commerce, and at the same time greatly reduce the waste and extend the use of the waters; . . . and that the direct benefits would comprise an—

	£
"Annual saving in transportation	50,000,000
,, ,, ,, flood damage	30,000,000
,, ,, ,, forest fires	5,000,000
,, ,, ,, cheapened power ..	15,000,000
Annual saving in soil erosion or benefit through increased farm production ..	100,000,000
Total ..	£200,000,000

"It is estimated that the income derived from power developed by works for the improvement of navigation, if utilised at current market rates, . . . would alone compensate the entire cost of maintenance and continued development after the initial expenditure of £200,000,000 as a working capital."

Much can be done to ascertain the approximate possibilities of a potential scheme before deciding to incur the heavy cost of a detailed survey by—

(1) Installation and continuous recording of river gauges on all likely channels.

(2) Installation and recording of rainfall gauges at suitable places.

(3) Observation of river discharges for a series of gauge readings.

If a reasonably long record of rainfall exists, the determination of the run-off for a few years will serve to give a relation between precipitation and run-off which can be carried back as far as the rainfall records go. The initiation of operations (1) to (3) costs little, and no time is lost in collecting the more important data.

While this is true, it should be borne in mind—

(1) That to be of reliable value from a commercial point of

view the hydrometric studies must give a continuous record for a number of years, and show not only the minimum low water flow, but also the maximum flood conditions that have to be met in designing the head works.

(2) That the investigation of suitable rivers should include contour plans of the sites, profiles along the entire power reach of the river, and along the banks; also studies of lakes or lochs for storage, where they exist, and of the possibility of interconnecting two or more such lakes to feed one large project. These studies should be in sufficient detail to allow of preparing preliminary plans and estimating capital and operating costs, in order to demonstrate the capacity available and the commercial feasibility of development.

(3) That to develop the most obvious power site on a river without full investigation of the whole power reach of the river may not secure, and may make it impossible to secure, the maximum advantageous use of the river by the development of two or more sites.

(4) That to secure the maximum possible use of a river the investigations should therefore be made by the Government rather than by private interests.

(5) Especially is this the case where storage may be developed, in order that the maximum possible storage may be secured, and that the water may be equitably distributed to, and the cost of the works equally borne by, the various interests benefited. Proper storage may greatly improve flood conditions and enhance the value of land as well as increase the power available.

(6) That without complete surveys the capacity of a river cannot be accurately judged. The pondage created by the dam will in many cases more than take care of the daily peak load, thus increasing the power available beyond that due to the minimum low water flow, and this may be still further increased by storage at the head waters. The power capacity of a river may sometimes be increased by such means by 100 or 150 per cent. or more.

Development in Other Countries.

The Committee would draw attention to the intense interest in the development of their hydraulic powers which has been in the immediate past and is at present being shown by the

majority of the European States. This has been largely due to the great demand for power for the manufacture of munitions, combined with the general world shortage of coal. In the countries at war, the normal development has been accelerated in a very large degree. Thus in *France* since the end of 1915, some 850,000 h.p. has been actually put into commission or is in process of active development, and by the end of 1921 the country will have at least 1,600,000 h.p. under control, as compared with 750,000 h.p. before the War.

In *Italy* concessions totalling over 250,000 h.p. are already under way, while favourable consideration has been given by the Government to concessions totalling another 50,000 h.p. It is estimated that schemes totalling 2,000,000 h.p. will be in working operation in a few years. In *Sicily* also large projects are under active consideration.

In *Russia* the National Economic Council is reported to have undertaken the erection of various hydro-electric stations capable of supplying power sufficient for all the industrial requirements of Petrograd.

In *Norway*, *Sweden*, and *Switzerland* large developments have been in train, while in *Iceland* a hydro-electric scheme contemplating the development of over 1,000,000 h.p. from the River Fjorsaavasdraget is planned by an Icelandic Company. In Sweden the three State hydro-electric stations at Trollhätten, Porjus, and Alfkarleby now develop about one-third of the aggregate output of electric energy in the kingdom. Their present output of 800 million k.w. hours per annum is to be largely increased in the near future. The State also owns a number of other important falls which are estimated as being capable of developing between 2,000 and 3,000 million k.w. hours.

In *Spain* great interest is at present being taken in hydro-electric developments. By a Royal Decree, dated September, 1918, the regulations governing the granting of water-power concessions have been unified and brought up to date. Water-powers exceeding 1,000 b.h.p. may now only be developed as a result of such concession granted by the Provincial or Imperial Governments. Various large projects are under consideration, including one on the Douro, which is estimated to be capable of giving some 350,000 h.p.

Germany.—During the War many extensions of hydro-

electric schemes appear to have taken place, and many further schemes are projected. In Bavaria a large project has been initiated, to be financed in part by the State, in part by the various towns interested, and in part by existing stations. Of a capital of 10 million marks, the State subscribes 5·1 million marks, and so has a controlling interest in the scheme. The towns of Munich, Nuremburg, and Augsburg each subscribe 400,000 marks. The State is to have the option of taking over the whole concern at the end of fifty years at a price which represents the cost of the first installation and of extensions, subject to a reduction of 1 per cent. per annum. The total cost of the scheme, which is to be raised by loans, is about 78 million marks.

In Wurtemburg and Saxony the State is to participate in the development and administration of electricity works, while Prussia also seems to be committed to the State control of hydro-electric schemes.

Austria.—In Austria the late Government had drafted a comprehensive plan for the development of the hydro-electric resources of the country, the eventual object being the electrification of some of the principal railway systems. At the instance of the Austrian Railways Department, some 433 falls with an aggregate average yield of 1,500,000 k.w., have been surveyed. Of these 17 have been secured outright, while 7 additional concessions are pending. The aggregate of these 24 schemes totals 135,000 k.w. In addition the State Department has exercised its right of option in 16 cases in which concessions had been granted to private concerns, and in 37 other cases steps for utilising the right of option have been taken. The present political unrest has, however, relegated these schemes to the background for the time being. Other large hydro-electric schemes have in the meantime been planned, and include an installation of some 25,000 k.w. on the Talebor River, and one of some 120,000 k.w. on the Wallsee.

It is estimated that in Russia some 20,000,000 h.p. is available, of which 1,000,000 h.p. is developed; in Brazil 26,000,000 h.p. with 320,000 h.p. developed; while over 1,000,000 h.p. is now developed or in course of construction in Japan.

The Empire's position in water-power development at the present time compares unfavourably with that of its com-

mercial competitors. Statistics of available and developed water-supply have recently received considerable attention both by Governments and private interests. The latest available figures are those compiled by Mr. Arthur Surveyer, of Montreal, Canada, a member of the Advisory Council for Scientific and Industrial Research, and by Professor Luigi Luiggi.

The summarised figures show the following:

	Hydraulic Horse-Power Available.	*Hydraulic Horse-Power Developed.*	*Per Cent. of Available now Developed.*
Europe: Germany, Italy, Switzerland, Spain, Sweden, Austria-Hungary, France, and Norway ..	47,300,000	8,450,000	18·0
United States	32,000,000	6,500,000	20·3
British Empire	60,000,000	3,000,000	5·0

Of the total developed water-power in the British Empire, about 72 per cent. is in Canada. If the foregoing table be reconstituted, so as to show Canada and the United States together as North America, it becomes:

	Hydraulic Horse-Power Available.	*Hydraulic Horse-Power Developed.*	*Per Cent. of Available now Developed.*
Europe	47,300,000	8,450,000	18·0
North America	50,800,000	8,805,000	17·3
British Empire (except Canada)	41,200,000	695,000	1·7

Summarised in this way, the figures afford striking evidence of the relative scope for development throughout the Empire.

Investigation and Development in the British Empire.

The state of investigation and of development of the water-power resources of the Empire is briefly reviewed in the following pages.

Great Britain and Ireland.—In 1918 a Committee was appointed by the President of the Board of Trade to investigate the water-power resources of the United Kingdom. A Sub-committee of this Committee has been appointed to report upon the water-powers of Ireland. The main Committee issued its first interim report in 1919. At this stage the Committee had carried out preliminary investigations of nine of the more promising sites in Scotland, of the most promising areas in North Wales, of the English Lake District, and of certain typical English rivers. By far the greater part of the water-power of the United Kingdom is situated in Scotland, and from the nine sites examined for the Committee, some 183,000 continuous h.p. is available. This is only a fraction of the total water-power in the country, and it would appear probable that the possible output is well over 1,000,000 h.p. of which a considerable proportion is commercially feasible under present conditions.

Over a considerable extent of the area of the Scottish Highlands the rainfall exceeds 60 inches per annum, and this area is studded with lochs, which form natural storage reservoirs at considerable elevation. Moreover, no part of this area, which is some 12,000 square miles in extent, is more than 20 miles from some arm of the sea or from the Caledonian Canal.

The largest installation as yet developed in the United Kingdom is the Kinlochleven Works of the British Aluminium Co. Although the drainage area is only 55 square miles, the high rainfall, amounting to 70 inches per annum, and the large fall of 920 feet, are sufficient to give an output of about 30,000 e.h.p. These works are now being increased by the addition of the power to be obtained from Loch Eilde Mor.

While in England there are larger rivers than in Scotland, there are fewer natural lakes, and the possibility of water-power development is restricted by the general lack of elevation.

The powers are, in general, small and widely distributed, and must usually be developed without storage by utilising the natural river flow, as has been done, for example, on the Dee at Chester.

Like England, Ireland's possibilities of power appear to lie in her great rivers. A large part of the interior of the country forms a flat plateau at no great height above sea-

level. On this plateau flow large sluggish rivers, the Erne, Corrib, Shannon, Bann, Lee, Inny, etc., most of which have a steep fall to the sea for the last few miles of their length. This feature of the rivers makes them valuable for power production. The best of the lochs lie in agricultural country, and the raising of their levels would flood much valuable arable and pasture lands. The amount of power available is probably considerable, and it is hoped that the Final Report of the Board of Trade Committee will afford some idea as to its actual amount.

In the mountainous area of North Wales, where the rainfall is high, two power installations have already been established, developing some 12,000 e.h.p. There are possibilities of further development in this region which are well worth investigation.

While the possible water-powers of the United Kingdom are comparatively small, yet, occurring as they do at no great distance from industrial regions, they are relatively valuable, and every effort should be made, by close investigation, to ascertain their commercial value at an early date.

A second interim report of the B.O.T. Committee, issued in June, 1920, deals with the suggested machinery of control of the water resources of Great Britain. It recommends the formation of a Board of Water Commissioners, to whom all questions of the allocation of water-supplies, whether for power or other purposes, shall be referred, and whose duties shall include the systematic collection of stream-flow and relevant data.

A third interim report issued in December, 1920, deals solely with the question of tidal power, with special reference to the possibilities of the Severn Estuary. The Committee concludes that while insufficient data are available to enable a definite opinion as to the economic practicability of the scheme to be expressed, it merits further detailed investigation. It offers a possibility of an output of some 350,000 h.p. daily over a 10-hour working period, corresponding to a saving of 1,270,000 tons of coal per annum on the basis of the consumption in modern large coal-fired power stations.

British India.—The question of the development and utilisation of water-powers in India was discussed at some length at the meetings of the Indian Industrial Commission between

1916 and 1918. The evidence brought before the Commission emphasised the meagreness of the available information and the urgent need for further investigation, and as a result of their recommendation the Government appointed the Chief Engineer of Irrigation in the United Provinces and the Electrical Adviser to the Government to report on the possibilities of promising water-power sites. This work is now in progress, and Mr. J. W. Meares, the Chief Engineer to the Hydro-Electric Survey, has already issued a valuable preliminary report.* This shows that although a large number of possible sites have been brought to notice, very little precise information as yet exists in regard to the majority of them. Local Governments in India have each been asked to nominate an experienced officer of the Public Works Department with a view to carrying out further and detailed surveys as speedily and thoroughly as possible, and arrangements have been made to ensure that these investigations shall be carried out on uniform lines. The Government of India anticipate that the results of a number of such investigations will very shortly be available.

Since the issue of the preliminary report much additional work has been done by Mr. Meares, and the present state of investigation would appear to show that some 213,000 k.w. is already developed; 55,600 k.w. is under construction; 1,194,000 k.w. (twenty-four-hour power) has been investigated; 1,102,000 k.w. (twenty-four-hour power) is known and worth examination; while probably over 3,000,000 additional k.w. has not yet been examined. The total forecasted amounts to 5·6 million k.w. on minimum flow; 7·5 million k.w. on "average minimum flow"; and 12·7 million k.w. on maximum development.

Mr. Meares considers these figures extremely conservative.

The power problem in India is in general complicated by the urgent necessity for conserving as much water as possible for irrigation purposes. There are numerous great perennial canals with drop falls at fairly short intervals; there are also numerous large reservoirs. At first sight it might seem that these sources of power should be utilized. When carefully examined most of these are, however, found to be useless for

* Preliminary Report on the Water-Power Resources of India Calcutta, 1919. Superintendent of Government Printing.

power purposes, owing to the paramount necessity for operating the works with reference to irrigation requirements. Periodical closures are necessary for the execution of repairs; the canal branches are operated in rotation so as to lessen loss by absorption; and in times of heavy rainfall it may be necessary to close the canal completely. All these methods of working are directly opposed to power requirements.

Over the greater part of the country there are few perennial streams, and storage reservoirs for conserving the high rainfall of the monsoon season would be necessary. In Bombay, on the Eastern side of the crest of the Western Ghats, the mean rainfall is approximately 150 inches per annum, the whole of this rainfall occurring within four months. Many of the elevated valleys of the Ghats lend themselves to the construction of storage reservoirs, and, owing to the geological conditions, a very large proportion (up to 90 per cent.) of the rainfall may be collected and stored.

The Tata Hydro-Electric Undertaking receives its water-supply from three such valleys. The total catchment area is only 22 square miles, but this is sufficient to give 100,000 e.h.p. for 3,600 hours per annum.

Other projects of a similar type are under investigation in the Western Ghats. It is estimated that a continuous 300,000 e.h.p. may be obtained from the Koyna River alone; that approximately 100,000 e.h.p. may be obtained from each of the rivers Vaiturna and Kali Nadi, and about the same amount from the Andrha Valley. It is estimated that a continuous 20,000 e.h.p. is available at the Kali Nadi, Gersappa, and Lushington Falls, and that, by a combined system of storage reservoirs, suitable also for irrigation purposes, a continuous 50,000 e.h.p. might be developed from this system.

The north-west corner of the United Provinces would also appear to be a promising locality for early development. There are possible sites on the Ganges, Tons, Jumna, Paisani, and Kosi Rivers, and at present the erection of a generating station on the Jumna is under consideration. It is estimated that from 40,000 to 50,000 h.p. can be easily and economically developed on the rivers Jumna and Tons, and as this region is thickly populated, there would be immediate markets for energy for the operation of cotton, rice, sugar, flour, oil, and saw mills, and for other industrial undertakings.

There are also known to be many promising sites in the Central Provinces, and the aggregate of power should be large; but little detailed information is available.

In Mysore there is the very successful Government undertaking on the Cauvery River. As now extended, the power-house has a capacity of over 22,000 e.h.p. The power is transmitted some 90 miles to the Kolar goldfields and to Bangalore and Mysore, respectively 57 and 37 miles distant.

The provinces of Bengal and Madras do not appear to show any great possibilities in the matter of hydraulic power. The question of utilising the lake at Periyar for power purposes is, however, now being investigated.

In the Native State of Kashmir an installation on the Jhelum River at Mohora is designed to develop 20,000 h.p., and transmits its power to Baramula and Srinagar.

Under existing regulations, the sanction of the Secretary of State is necessary for the granting of any concession—

(*a*) If the concession is intended to endure for more than ten years and is not accompanied by an unconditional power of revocation or cancellation, and imposes on the revenues of India an annual liability in excess of 50,000 Rs.; or

(*b*) Imposes on such revenues, expenditure, or liability to damages in excess of 1,200,000 Rs.; or

(*c*) Involves the cession of property or rights estimated in value at more than 1,200,000 Rs.;

and the sanction of the Indian Government is necessary—

(i) If the period in Clause (*a*) exceeds five years and the liability 5,000 Rs.;

(ii) If the sum in Clauses (*b*) and (*c*) exceeds 100,000 Rs.

Below these amounts the local Government can sanction the concession.

A number of rain-gauge stations have been established in the catchment areas of rivers in Bombay, and the detailed record of the rainfall is available in the offices of the Executive Engineers concerned. Also a record of river gaugings in the Ghat area is published annually. While these observations are being made with the primary object of developing irrigation schemes, any information thus collected, if required for the consideration of a hydraulic power scheme, may be obtained

on application to the Secretary to Government, Public Works Department (Irrigation).

The Joint Secretary to the Government of Madras P.W.D. states that on the Nilgiri Plateau the water-power prospects are very promising. Three rivers running off the plateau have been gauged, and the prospect of their being successfully utilised is practically assured. From the largest of these, with storage, a continuous supply of 100 cubic feet per second can be obtained and, as there is an almost precipitous fall of about 3,000 feet down to the plains, the power obtainable should be very large. Further gauging observations are being initiated to ascertain the maximum and minimum discharges of a number of rivers and to collect reliable data regarding the rainfall and run-off from different catchment areas.

In view of the Committee's recommendations (see p. 51) regarding the question of training in hydro-electric engineering, it is of interest to note that the Government of India have, as a preliminary measure, given instructions that in the major engineering colleges in the control of the Governments of Bombay, Madras, Bengal, and the United Provinces, a course of lectures should be given in this subject by an expert in hydro-electric engineering.

In general the hydraulic possibilities of India appear to be very great. The country possesses in abundance the minerals necessary for metallurgical development, the climate and land for the cultivation of cotton, flax, jute, and many other commodities, and an enormous population which, if trained, would provide abundant skilled labour. It is certain, too, that once it is determined by experimental trial for what crops and soils nitrogenous fertilisers can be used with profit to the cultivators, the demand for these, provided they can be produced at sufficiently low rates, will be enormous.

The development of Indian water-powers would appear to offer a most promising field to British manufacturers, and one in which some initial sacrifice would probably be amply repaid.

It would appear that under the Indian "Reforms" the question of hydro-electric investigation has now become a Provincial one, and as the Government of India can consequently grant no further funds for this purpose, there is some fear that the Local Governments may follow suit.

Ceylon.—The question of the utilisation of water-power in the island is under the consideration of a Committee appointed by the Local Government. The amount of power should be very considerable, but little definite information is available. Mr. H. T. S. Ward, M.Inst.C.E., estimates that at least 68,000 continuous h.p. is available even in the dry season at the falls of the Mahaweliganga. This is said to be a very conservative estimate. The water rights belong to the Ceylon Government. There are a number of rain-gauge stations on the 712 square miles of catchment area feeding the Mahaweliganga. Rainfall records for these are available for periods varying from five to forty-five years. The mean rainfall is 115 inches per annum.

The flow of the Walawe Ganga is about one-half that of the Mahaweliganga, but the information as to the fall of the former river is not sufficient to enable any estimate of its probable power to be made.

The Committee has received a copy of a report by Mr. Meares, on the Laxapana-Aberdeen Hydro-Electric project in the Central Province, Ceylon. This involves the utilisation of the waters of the Kehelgomu Oya and the Maskeliya Oya, under a head of about 1,950 feet. The complete scheme is capable, with little storage, of giving a continuous output of 100,000 b.h.p., which could be increased very largely by additional storage.

British East Africa (*Kenya Colony and Protectorate*).—A Report from the Director of Public Works of the East African Protectorate states that the highlands of the Protectorate, where development of power schemes is chiefly proceeding, are not at all badly supplied with water-power resources. On some few sites it is estimated that very substantial developments, ranging from 5,000 to 50,000 h.p., are possible. At the present time, three projects, each of about 2,000 h.p., are being negotiated within 50 miles of Nairobi, and numerous smaller projects are being developed.

There is a general lack of definite data as to the possibilities of most of the water-powers. In 1918, however, Government sanction was accorded to the appointment of a special Water Engineer to organise and carry out, so far as funds may allow, a hydrographic survey of the Protectorate. The Committee had an opportunity, during 1919, of meeting the Engineer,

who explained very fully the present position regarding water-power development in the Protectorate, and submitted a series of Memoranda, which are available for reference in the offices of the Conjoint Board at Burlington House.

While the present financial resources of the Protectorate do not appear adequate to allow of any extended investigation being carried on at the moment, in view of the apparent water-power possibilities it is to be hoped that such investigation may be found possible in the near future. It is suggested that the investigation of the hydrographic features of the Protectorate, of Uganda, and of the territory previously forming German East Africa, might be co-ordinated under central control. Since the Upper Nile Basin is partly in the three dependencies, and many of the rivers traverse more than one of them, it would appear desirable that river investigation should be controlled as little as possible by intercolonial boundaries.

The probable power resources of Uganda in the Nile Basin are greater than those of either of the other two dependencies, and the possible transmission of power from the Ripon Falls to the settled districts of British East Africa, west of the Rift Valley and north of the Uganda Railway, may acquire importance in the near future. Moreover, the unification of water laws, in the initial stages of development, is desirable.

All water-powers in the Protectorate are definitely Crown property, and in the past the Director of Public Works has acted as custodian of public rights in this respect. No grants for the use of water-power are made in perpetuity. Up to the present time there has been no legislative enactment guiding the action of the Department of Public Works in dealing with water rights. A draft Ordinance for dealing with this question has been drawn up, and will probably be considered at an early date in the Legislative Council.

An Electric Power Ordinance on very progressive lines has recently been adopted, and, with the Water-Power Ordinance on similar lines, the Protectorate promises to be in a strong position to foster and develop supplies of electrical energy over extensive areas of the country on very favourable terms.

British Guiana.—A preliminary survey of the water-powers of British Guiana was carried out in May, 1919, by Mr. S. X. Comber, M.Am.Soc.C.E., under the instructions of the Govern-

ment of the Colony. This report is available for reference at the offices of the Conjoint Board. The Government intends to provide automatic gauging stations on the Essequibo, Cuyuni, Demerara, and Potaro Rivers, which should give extremely valuable information.

The principal available water-powers lie on the Essequibo River, with its tributary the Potaro, the Mazuruni River, and the Cuyuni River. Other possible sources are the Demerara and the Berbice Rivers.

On the Potaro River, the Kaieteur Gorge has a total drop of over 1,000 feet. The Kaieteur Fall itself has a vertical drop of over 740 feet, the width of the head of the fall being about 400 feet when the river is full. In times of exceptional drought, however, the width shrinks to 50 or 60 feet.

To the north of the Kaieteur, a relatively small river, the Curiebrong, descends from the Kaieteur plateau by a fall at Amaila and a series of cataracts. After flowing for 15 miles or so from the Kaieteur Falls, the Potaro River, after receiving in its course the waters of some affluents, arrives at the mouth of the great Kaieteur Gorge and leaves the sandstone district at the Amatuk Falls. Here the river, flowing at a high velocity through a relatively narrow channel, descends about 30 feet, 20 feet of this being practically vertical. The volume of water at this fall is probably 30 per cent. more than at the Kaieteur. Twelve miles further on the Potaro, having had the volume of its water materially increased by affluents, flows over the great series of Pakatuk-Cobanituk-Aurituk Falls, where is a series of nine cataracts in a space of about 2 miles. The total drop of these cataracts is estimated at 20 to 25 feet. Below them the Potaro is joined by the Curiebrong River, and at a distance of about 15 miles from Aurituk traverses the Tumatumari Cataract with a total fall of from 16 to 20 feet. From the Kaieteur to Tumatumari the Potaro offers one long series of potential sites for water-power stations.

The Great Falls of the Essequibo River are a long series of rapids or low cataracts about 6 miles in length, where the Essequibo River, with an average width of about $1\frac{1}{2}$ miles, descends to its tidal waters. The total fall of these cataracts is unknown, but is very appreciable.

The Mazaruni, a river of about $\frac{3}{4}$ to 1 mile in width, is constantly interrupted in its course by rapids and cataracts.

The lowest series of rapids and cataracts, extending practically from Maripa to Marshall Fall, a distance of perhaps 5 miles, has probably a similar total fall to that of the Great Falls of the Essequibo River.

On the Cuyuni River, a narrower but deeper river, not much more than ½ mile across above the lowest cataract, there are two sites available for water-power, the upper one being at Arawak-Matope Falls, about 18 miles from the junction of the river with the Mazaruni River, where the river falls perhaps 12 to 16 feet, or possibly more; and the lower ones, the Kamaria-Akaio series of cataracts, starting at about 8 miles above the junction of the rivers, their total fall, in a distance of about 3 miles, being similar to that of the Great Falls of the Essequibo.

There are also numerous falls, cataracts, and rapids in the interior of the Colony, the details of which are very little known, while the distance from the coastlands and the sparsely inhabited state of the country where they occur remove them from any practical potentiality as power stations.

No actual measurements or river gaugings have as yet been made by the Government of the Colony, and the foregoing estimates have no pretensions to any high degree of accuracy. Still, it is evident that the potential water-power of British Guiana is extremely large. Thus the Kaieteur alone at the fall and gorge, assuming a mean depth of 10 feet over the fall, offers possibilities of 2·5 million b.h.p. The power developable in periods of drought, assuming a width of 60 feet and a mean depth of 5 feet, would be about 125,000 b.h.p.

As very extensive deposits of bauxite have been proved in British Guiana, the country would appear to be exceptionally well situated for becoming an important producer of aluminium for the Empire.

In view of these facts the early investigation of the possibilities of the various large falls is well worth serious consideration.

Rainfall records have been kept at a number of stations in the Colony. The rainfall of the coastal districts averages about 100 inches per annum. In the forest regions it ranges from about 90 to 160 inches, with a mean value of about 115 inches. In the Savannah regions in the far interior of the Colony records have only been taken during the past seven

or eight years. The rainfall in this region is much less than in the forestal or coastal districts.

British Honduras.—A communication from the Governor of British Honduras has been submitted to the Committee, through the Colonial Office. This states that there do not appear to be any falls within 90 miles of Belize of sufficient volume to afford any appreciable supply of energy. There are, however, various rapids in remote parts of the Colony, of which only two, the Machaka and Monkey Falls on the Moho River, possess any appreciable fall. The Vaca Falls, about 90 miles from Belize, are about 700 feet high, and are capable of supplying at all times about 25,000 h.p., and in the rainy season about 1,000,000 h.p. Much further investigation would be required to determine whether any of these sites could be made industrially useful.

Australia.—Though comparable in area with the United States, there has as yet been no notable hydro-electric development in Australia. Except on the East Coast, the topography is too flat or the rainfall too low to provide the necessary conditions. Some of the large irrigation schemes are capable of being utilised for power production, but the aggregate of such possible power is small.

The only possibilities of considerable powers are to be found in the rivers draining the Great Dividing Chain of the East Coast. A large area of the district of the *Australian Alps*, situated partly in Victoria and partly in New South Wales, has a rainfall of 50 inches per annum, and the run-off is probably as much as 18,000 cubic feet per second. The level is high, Mount Kosciusko attaining an elevation of 7,200 feet, and the sea is distant less than 100 miles. There are plenty of opportunities for damming back the rivers, so that a considerable aggregate fall might be secured. Probably the possibilities of this region lie between 300,000 and 500,000 h.p. Among others, the following rivers appear to deserve careful inspection:—The Snowy, Tambo, Dargo, Wonnangatta, Thompson, Goulburn, Ovens, Mitta Mitta, Indi, Tumut, and Murrumbidgee.

In Victoria a scheme has been suggested to utilise the head waters of the Kiewa River. From surveys it is estimated that about 40,000 e.h.p. may be developed from this source.

The *Blue Mountains*, to the west of Sydney, form an impor-

tant high-level catchment. The altitudes attain about 4,000 feet, the rainfall is about 40 inches, and the run-off probably about 1·5 cubic feet per second per square mile. The physical character of the region, as a plateau deeply cut up by canyons, suggests the possibility of efficient utilisation of the run-off, and the available economic power is likely to be between 25,000 and 50,000 h.p. Already useful power schemes have been put forward for the Cataract and Warregamba Rivers.

The *New England Range* in New South Wales, and extending into Queensland, contains heights of over 5,000 feet, and descends steeply to the coastal lowlands. The rainfall averages about 50 inches per annum, and the available catchment is about 6,000 square miles. The available power probably lies between 200,000 and 500,000 h.p.

In 1914 the Government of New South Wales directed that a systematic preliminary investigation of the most important water-powers should be made, and some of these preliminary surveys have been carried out. Among the rivers already investigated or to be investigated are the Murray, Murrumbidgee, Tumut, Snowy, Shoalhaven, Hawkesbury, Warregamba, Hunter, Hastings, Macleay, Clarence, and Richmond. Although the Water Conservation and Irrigation Commission has published the results of various river gaugings, these refer to such rivers as are suitable for water-supply or irrigation rather than for power purposes. Certain new gauging stations have been and are being established in order to obtain data on which to base estimates of available power.

In Queensland the *Cairns District* offers useful possibilities. The effective mountainous catchment areas of the rivers entering the sea between Lucinda Point and Cairns are roughly 3,000 square miles, and the rainfall ranges from 50 to 140 inches. The available horse-power probably lies between 150,000 and 400,000 h.p. The Barron River Falls, 19 miles from Cairns, are approximately 1,000 feet in height, and it is probable that the river in their vicinity would yield at least 10,000 h.p. This district is favoured in respect of shipping facilities and is rich in copper, tin, and other minerals, so that a market could probably be found for any power likely to be developed.

The aggregate power suggested as being capable of economic development in the Great Dividing Chain is as follows:

Australian Alps	300,000 to 500,000	h.p.
Blue Mountains	25,000 to 50,000	,,
New England Range	200,000 to 500,000	,,
Cairns District	100,000 to 250,000	,,
Total ..	625,000 1,300,000	

As little in the nature of an actual hydrographical survey has been made, these estimates are of a very general nature. Sufficient, however, has been said to indicate that 1,000,000 h.p. may reasonably be expected from Australia.

In all cases the scheme would be somewhat expensive to develop, but in view of the general high cost of power in Australia, it would probably not be prohibitive. The possibilities are certainly sufficiently promising to justify a careful and extensive hydrographical survey.

New South Wales.—The Committee has received a copy of an Interim Report by Mr. Wm. Corin, the Chief Electrical Engineer, on the Gorge scheme for developing power on the Clarence River. From this it appears that at least 100,000 h.p. can be developed in the neighbourhood of the Gorge, while suggestions are made as to initial developments for utilising a portion of the power. Mr. Corin is at present engaged on a comprehensive report on the water-powers of the State.

Victoria.—The Committee has received communications from Mr. A. S. Kenyon, the State Water Engineer, from Mr. Nalby, the Secretary to the State Rivers and Water Supply Commission, and from the Secretary to the Electricity Commissioners, Melbourne. The latter body has had four survey parties in the field since the spring of 1919. From Mr. Nalby's memorandum, supplemented by the other communications, it appears that the total power at present developed in the State does not exceed about 1,000 h.p. There are installations on the Yarra, Barwon, and Loddon Rivers in which turbines are used for working flour mills, etc., subsidiary steam plants being provided for use when there is not sufficient water. These and a few minor plants, used generally for milling and mining purposes, are the only instances. The chief reasons assignable for this seeming neglect

lie in the great variation between (*a*) summer and winter flows; and (*b*) the annual flows in different years, the effect of which would render the power output of any but the smallest plants of too variable a nature.

This is illustrated by the following records of gaugings of the chief rivers from which power may be expected, taken between the years 1906 and 1918:

River.	*Gauging Station.*	*Mean Flow for One Month. Cubic Feet per Second.*	
		Minimum.	*Maximum.*
Upper Murray ..	Jingellic	105	19,400
Mitta	Tallangatta	32	13,500
Upper Goulburn ..	Eildon (4 years)	215	12,000
	Murchison (13 years)	20	21,000
Snowy	Orbost	206	12,000

Storage for irrigation purposes has been effected to some extent, and is likely to be extended in the future, and it might be supposed that the regulation of streams effected in this way would minimise the difficulty referred to. In practice it is likely that conflict would arise between the use of the stored water for irrigation and for power purposes in dry seasons when the natural flow of the rivers is low, thus to some extent nullifying the use of stored water for power purposes, as there is no doubt that irrigation interests should and would prevail.

An instance of this exists in the case of the plant on the Loddon River already referred to, which is largely dependent on the Laanecoorie Storage for summer supplies, and where the power requirements are of necessity made secondary to irrigation needs.

The principal stream in South-Eastern Australia is the River Murray. It is possible that on the head waters, which rise in very rugged, inaccessible country, sites for installations capable of developing several thousand horse-power may eventually be located; but from where the rivers enter the plain country, extending from Albury to the sea, power development on a considerable scale is not likely to be attempted on account of the very flat river grades—the total fall through-

out the distance of about 1,400 miles being only about 400 feet, the slope decreasing gradually from 9 inches per mile near Albury to about 4 inches per mile at the Victorian Border.

The most important scheme hitherto suggested relates to the utilisation of the head waters of the Kiewa River. These rise amongst the higher peaks of the State, and though the water volume is not very considerable, the available fall is great, about 3,700 feet. It is proposed to make use of the water in two drops of about 2,600 feet and 1,100 feet each respectively. The promoters of this project estimate a total output of about 30,000 k.w., but the data on which this estimate rests are meagre as yet. In this case the extremes of summer and winter flows are to some extent equalised naturally, the catchment being snow-covered for a considerable portion of the year. In addition to this natural advantage there are facilities for forming fairly cheap artificial storages.

Another important scheme refers to the waters of the Thomson River at the junction of the Aberfeldy, in the neighbourhood of Walhalla. In the same locality the Long Tunnel Gold Mining Company of Walhalla have proposed to utilise the waters of the Cascade Creek on the slopes of Mount Baw Baw, supplemented by a small storage at the head of the Creek near the summit of the mountain. The water flow in this case is small, but the head considerable, about 2,000 feet. The estimated output at the power station is 1,200 h.p.

Another somewhat vague proposal relates to the waters of the Snowy River, but the actual site of the power station in this case might be outside of the Victorian border. The promoters of the scheme are interested in the Kiewa River scheme, and propose to link up the two and work them as one project. Without having actually investigated the scheme, they have estimated an output of about 40,000 h.p.

The list is not by any means exhaustive, and, of course, does not in any sense represent the full possibilities of the State.

The Commonwealth of Australia : Tasmania.—Estimates have already been made of a few of the more promising hydraulic powers of Tasmania. The State Hydro-Electric Department has investigated the possibilities of the upper reaches of the Ouse, Arthur's Lakes, Lake St. Clair, the Dee, Franklin, and King Rivers. No complete survey of the water-power of Tasmania has, however, yet been made.

The late Agent-General (Sir John McCall) estimated the possibilities at about 400,000 h.p.

The Government Hydro-Electric Department is now surveying, as opportunity permits, the more promising sites. It is carrying out a survey of the King River Gorge on the Mount Lyell Co.'s railway with regard to the suitability of that part of the river for the installation of a second power scheme. It is estimated that 15,000 h.p. can be developed at King River Gorge, and this, taken in conjunction with the original power scheme of 45,000 h.p. on the river, will yield 60,000 h.p. If the scheme materialises the power generated will be sufficient to supply all mining and smelting works on the West Coast of Tasmania and will leave a surplus for manufacturing enterprises.

The general policy of the Hydro-Electric Department is to develop the water-powers of the State wherever this can be done profitably, and in accordance with this view the administration of the Department are urging on the Government the necessity for a complete survey of the water-powers of the State at as early a date as possible.

So far only three hydraulic installations have been developed. These are the Great Lake Scheme, at present developing something over 12,000 h.p.; the South Esk Scheme, developing 1,350 h.p.; and the Lake Margaret Scheme of the Mount Lyell Mining Co., developing 4,000 h.p. The Great Lake is on the central plateau, and with a catchment area of only 216 square miles, and with a head of 1,120 feet, is capable of developing 70,000 h.p. The plant is now being enlarged. Part of the power is to be used for zinc reduction and calcium carbide production.

At present the principal purchasers of power from the Hydro-Electric Department are the Hobart Corporation, for tramways and general municipal requirements, the Electrolytic Zinc Co., and the Hydro-Electric Power and Metallurgical Co., Ltd., which has installed works for the manufacture of calcium carbide. The present capacity of these works is 5,000 tons per annum, but it is proposed to increase this. It is estimated that the electrolytic zinc plant may eventually absorb up to 26,000 h.p. Other contemplated industrial developments involving the purchase of power from the Hydro-Electric Department include a woollen mill and

works for smelting steel scrap, and there would appear to be every prospect of a ready demand for all the hydraulic power which can be developed by the Department.

Tasmania certainly should be capable of developing a relatively large amount of hydraulic power, for the rainfall exceeds 100 inches per annum over a large area of the mountainous region of the west, and there is no doubt that much of this area has a run-off of as much as 4 cubic feet per second per square mile.

It is probable that Sir John McCall's rough estimate of power is well within the mark. In view of the shortage of water-powers in Australia, and of the future demand of the Commonwealth for nitrogen products, etc., there should be no difficulty in finding a market for the output of all the energy which can be developed in Tasmania.

Papua (*British New Guinea*).—The following data are from a Report submitted to the Committee by R. E. Stanley, Esq.

Papua, or British New Guinea, has an area of approximately 90,540 square miles. It is for the most part mountainous even to the off-lying islands, with the exception of perhaps a few coral islands scattered about its coastline, and a portion of the mainland in the Western Division to the extent of about 18,000 square miles. Its mountain systems are complex, and reach an altitude of over 13,000 feet in Mount Victoria. The main Cordillera occupies the central portion of the mainland, running more or less parallel with the coastline near its south-eastern extension, but trends northerly towards the late Anglo-German boundary. Proceeding westerly, another system is seen in the Albert Mountains, 6,000 feet, which continue and connect with the ranges north of the Gulf of Papua. Still further west, and broken from the former, are Mounts Donaldson and Blücher, 2,000 and 5,000 feet respectively. These are offshoots from the Victor Emmanuel Range, 10,000 to 12,000 feet. From these huge mountain systems many large rivers flow carrying tremendous quantities of water to the coast. The largest of these rivers is the Fly with three large tributaries—the Strickland, Alice, and Palmer—which take their source in the Western Cordillera. The Fly and its tributaries drain practically the whole of the western portion of the Division. An estimate has been made, at a point above the tidal influence, of the quantity of water discharged by the

Fly, which is about 650 miles in length. At the point referred to the river is 600 yards wide, 40 feet deep, and travelling at 3½ miles per hour, and is discharging some 327,500 cubic feet per second. During Sir William Macgregor's expedition up the Fly more data were obtained in connection with the amount of water carried by the Fly and its tributaries. These are as follow:

FIGURES TAKEN NEAR THE CONFLUENCE OF THE FLY AND ITS TRIBUTARIES.

River.	*Width in Yards.*	*Depth in Feet.*	*Rate in Miles per Hour.*	*Cubic Feet Discharged per Second.*
Fly	302	42	1·5	83,500
Strickland ..	420	32	3·3	196,000
Fly	207	15	1·5	20,500
Alice	152	12	2·0	15,700
Fly	130	10	3·0	17,150
Palmer ..	120	18	2·5	23,750

A rough estimate can be made of the other rivers along the coastline, the most important of which are the Bamu, Turama, Kikori, Purari, Vailala, Tauri, Lakekamu, Biaru, Angabunga, Vanapa, Kemp Welch, Ormond, along the south coast, and the Musa, Barigi, Kumusi, Ope, Mambare, and Gira along the northern coastline. These rivers, which take their sources in the Victor Emmanuel, Sir Arthur Gordon, Albert and Owen Stanley Range respectively, have many important tributaries with a tremendous fall in a short distance.

The most important centre appears to be that portion of the main range near the watershed of the tributaries of the last-named rivers. For instance, the Rouna Fall, situated on the Laloki River, is within easy distance of Port Moresby, and is capable of generating between 20,000 and 22,000 h.p. The falls have a direct drop of 350 feet, but a maximum fall of 800 feet is available in 4 or 5 miles. Below the falls the Laloki joins the Goldie, a larger tributary, then the Brown, and finally empties itself into Galley Reach, near the tributaries of a still larger river called the Vanapa. It was estimated that the Laloki discharges 20,000 cubic feet per second, and this is one of the smallest of the rivers and a branch tributary.

In another instance, at the head waters of the Irura River (a tributary of the Musa in the North-eastern Division near Mount Obree), there is a fall of 2,500 feet in 2 miles. The river is about 60 feet wide and travelling at a rate of 10 miles an hour, practically 8,800 cubic feet per second. This is representative of one of the many mountain tributaries in Papua, and by no means the largest.

Taking all the rivers of any size, with their tributaries, in the Central, North-Eastern, Kumusi, and Mambare Divisions, it is estimated that the available horse-power would be somewhere in the vicinity of 6,000,000; and if we include the huge river systems in the Gulf, Delta, and Western Divisions, 10 million h.p. would be well under the mark.

In addition to the 10 million h.p. available from Papua itself, it is estimated that the occupied territory of German New Guinea affords possibilities of between 7 and 10 million h.p.

This accumulation of energy in a country of approximately the same size as the British Isles would appear to afford the means, at some future time, of opening up industries demanding large blocks of cheap power, on a scale hitherto undreamed of in the Southern Hemisphere.

New Zealand.—The physical characteristics of the two islands forming New Zealand render the country particularly well adapted for providing large stores of water-power, and for facilitating their development. The backbone of high mountains leads to heavy precipitation from the moist westerly winds, giving a mean rainfall of some 50 inches for the whole of the Dominion, while over a large portion of the South Island, the rainfall exceeds 100 inches per annum. The mountain ranges are studded with extensive lakes, situated above a deeply indented coastline. The mountains of the Southern Alps attain a height of over 12,000 feet, and support many glaciers of large size which act beneficially in equalising the run-off throughout the year.

Reports by Mr. P. S. Hay and Mr. L. M. Hancock, published in the New Zealand Parliamentary Papers of 1904, gave a list of seventy-two important and promising schemes, and placed the economically workable water-powers of the Dominion at 3,700,000 b.h.p. on the turbine shafts. Of this, 500,000 h.p. is found in North Island and 3,200,000 in South Island.

Since Mr. Hay's report of 1904, the Public Works Department has examined further schemes, adding to the original list. The latest and most complete statement is published in the New Zealand Government Year Book for 1914.

This table gives particulars of the more important available water-powers exceeding 1,000 h.p., showing also the nearest city or actual or potential port.

According to this report, the total available power is about 3,822,000 b.h.p. This is at the rate of about 37 h.p. per square mile of territory, or 3·5 h.p. per head of the population.

The power actually developed and in use in 1916 is given in the Government returns as 42,600 b.h.p. Many other projects are, however, in course of construction or under consideration.

A scheme for the development of three important sites in the North Island has been prepared. From these it is proposed to develop 130,000 h.p., requiring a plant capacity, in the main power stations, of 160,000 h.p. From these stations at Manganao, Waikaremoana, and Arapuni, a network of transmission lines, 1,420 miles in length, distributes the power over the whole of the Island. The scheme is intended to render power available for every householder in the Island and for any industry; also for main line electrification light railways, and for coal and other mines. The sources mentioned are capable of supplying much more power than it is proposed to develop under the present scheme, and an ample reserve remains for any probable future demands. When these schemes are completed the total water-power developed in New Zealand will be approximately 180,000 h.p., but, as this is only a small fraction of the available power, it is apparent that the possibilities of future development, when the demand for power arises, are very bright.

A report is also in course of preparation regarding the development of water-power in the Province of Southland.

Various new industries depending on the supply of electric energy are either started or are proposed, and it seems clear that the Government will be drawn into extensive hydro-electric development for the whole of the Dominion.

As regards State control, the Public Works Act of 1908 vests the sole right to use water-power in His Majesty, subject to any existing rights, and gives the Government the right

to develop, or to delegate such power to any local authority, or, outside a mining district, to any person or company, subject to conditions. Advantage has been taken of this in several cases, the right in the case of local authorities being issued free of royalty, and in the case of private individuals developing water-power for electrical distribution, subject to a royalty of $\frac{1}{20}d.$ per unit generated.

The outlook for New Zealand, at the dawn of what promises to be an era of unexpectedly great electro-chemical and electro-metallurgical activity, is most promising.

As a centre for the manufacture of nitrogen products, aluminium, calcium carbide, and the like, its situation is ideal. The fundamental requirement, a great excess of energy over the power needs of the country, is provided.* Further, that power is convenient to the coast; in some of the largest schemes the generating plant will be actually on the coast, on deep-water harbours.

To quote Mr. Hancock:—

"The manufacturing of all Australasia and a great portion of the Orient could be done here better and cheaper than anywhere else. Being so near these markets, with this unlimited power, and having a climate suited to a degree to manufacturing purposes, the possibilities of the colony, are almost beyond the bounds of fancy."

South Africa.—Little information is available regarding the water-powers of the Union of South Africa.

The Governor-General reports that a systematic survey of water-powers in South Africa, commenced in the latter part of 1917, is now in progress. In view of the great shortage of qualified staff, the work is at present being confined to a general cataloguing and classification of water-powers. At a later date it is intended to investigate the more promising powers more fully.

Owing to the seasonal character of the rainfall throughout South Africa, the flow of the rivers either is greatly diminished, or entirely ceases, during a considerable period in each year, and their value as sources of power is correspondingly diminished. It is, however, known that a number of important

* In 1904 the total developed boiler-power in the country, including all locomotives, was given as 250,000 h.p.

falls occur, particularly on the eastern slopes of the Drakensberg Range, some of which are perennial and capable of development. Some energy may also be developed on the Vaal and Orange Rivers and the Mooi River of Natal and the Transvaal.

Rhodesia.—In Rhodesia the rivers capable of developing large powers are in general very remote from present centres of industry, and few powers have as yet been developed.

There are three great river systems in Southern Rhodesia—the Zambesi, the Sabi, and the Limpopo. Of these the Zambesi is the more important. The 1918 Report of the Rhodesian Munitions and Resources Committee gives details of a gauging of this river at a point 5 miles above the Victoria Falls. This gauging was carried out from the middle of April to the middle of December, and, presumably, gives the low-water flow for that particular year (1905). The results show that the volume of water was then 11,750 cubic feet per second. It is estimated that the available fall is 315 feet, which would correspond to an output of about 350,000 b.h.p. No definite data are available as to the flood power. At the Kariba and Mapata Gorges the river offers further possibilities, and units of 5,000 to 10,000 h.p. could probably be installed.

Of the rivers in the Zambesi system, only the Hunyani, Ruia, Mazoe, Inyagui, and Nyagadzi offer any possibilities of power. The Hunyani cannot be relied upon for uniform flows of any magnitude.

The other rivers of this system have a more or less uniform flow. It is worthy of note that in this region, not only does the uniformity of flow increase, but also in rivers of equal catchments the percentage of run-off increases as their directions bear round from West to East.

The *Limpopo* and its feeders offer practically no possibilities owing to the great variability of flow, the flatness of the gradients, the sandy nature of the bed and banks, and the large amount of silt carried in suspension.

The *Sabi* river system offers greater possibilities. Its feeders have a fairly uniform supply and steep gradients with occasional falls, and it is estimated that it should be possible to develop some 90,000 h.p. from this system.

Assuming that 75,000 h.p. can be usefully developed at the

Victoria Falls, the resources of Southern Rhodesia total about 220,000 e.h.p., made up as follows:

Victoria Falls	75,000	e.h.p.
Kariba Gorge	10,000	„
Mapata	10,000	„
Ruia River	5,000	„
Mazoe River	5,000	„
Inyagui	5,000	„
Nyagadzi	5,000	„
Sabi System	91,000	„
Plateau	13,000	„
Total ..	219,000	„

Large areas in the neighbourhood of the Sabi Rivers consist of rich alluvial plateau land, which only requires irrigation to render it capable of bearing ample crops of sugar, cotton, rubber, etc., and as water is plentiful and only requires pumping, there would appear to be an immediate use for any such power as could be developed, in the irrigation and agricultural development of the region. The success of such a scheme would, however, depend on facilities for economical transport to Beira or the Union. The district is, moreover, rich in deposits of coal, copper, and other minerals, which are at present not developed owing to the large cost of power and the lack of transport facilities.

The possibilities appear sufficiently promising to warrant a thorough hydrographical survey being carried out.

West Africa.—It is estimated that some 250,000 h.p. is available from the rivers of the Gold Coast. In Nigeria the Kwa River is said to be capable of developing between 60,000 and 70,000 h.p.; the Calabar at Uivet, probably between 30,000 and 40,000 h.p.; and the Niger, between Jebba and Lokoja in the Northern Province, probably at least 150,000 h.p. A report from the Central Secretariat of Nigeria states that the entire property in, and control of all rivers, streams, and water-courses throughout the Dependency, is vested in the Crown, except for any express grants made before the Minerals Ordinance of 1916. The rainfall of various stations is given in the Blue Book of Nigeria, Section G.G.

Federated Malay States.—Information from the Director of

Public Works indicates that it is not possible to state even approximately the potential horse-power of the Federated Malay States. There are several large rivers, notably the Perak and the Pahang, from which power could be developed, but the localities are too remote for any present use to be made of the power.

Altogether some 11,250 h.p. is at present developed hydraulically; of this, 8,800 h.p. is used on mines for hydraulicking, and 2,450 h.p. for hydro-electric plants. All but 300 h.p. of this was used for power purposes on mines. With the exception of mining, there appears to be little demand for power at present.

There are a fair number of records of rainfall in the various small towns throughout the States, some extending over twenty years. The greater part of the country is covered with jungle, and it has not been possible to take records in such localities.

A beginning was made about four years ago to record the discharges of weirs which are likely to be useful for irrigation purposes, and these records are to be extended. As yet, however, the amount of information is very small.

Canada.—During recent years the Canadian Government, through the Dominion Water-Power Branch of the Department of the Interior, has devoted much attention to the systematic examination and development of the hydraulic resources of the Dominion, and the data, as regards the largest, most readily available, and most promising water-powers are sufficiently complete to permit a reasonably close idea of their possibilities to be obtained. These data are published in a series of some twenty-four reports issued by the Dominion Water-Power Branch. This Department has instituted a comprehensive system of mapping, indexing, and filing all available information concerning every important water-power throughout the populated portion of the Dominion. This system has been developed in collaboration with all the Provincial Authorities, and is intended to form a clearing-house from which all available information regarding the water-power and allied resources of any given district can be immediately supplied. Much information is also contained in the reports of the Commission of Conservation, and in the Annual Reports of the Hydro-Electric Power Commission of Ontario.

In view of the fact that hydro-electrical development in Canada has attained a stage far in advance of that as yet obtaining in any other part of the Empire, the following information as to the organisation existing in the Dominion for the collection of information as to water resources and their developments may be of interest.

These organisations are both Federal and Provincial.

Federal.—(*a*) The Department of the Interior operates through the Dominion Water-Power Branch and the Irrigation Branch.

1. *The Dominion Water-Power Branch—*

(1) Carries on stream measurement work in British Columbia under the name of the British Columbia Hydrometric Survey, and co-operates with the Provincial Water Rights Branch.

(2) Carries on all power and storage investigations in Alberta and Saskatchewan, and co-operates with the Federal Irrigation Branch in these two provinces.

(3) Carries on all stream measurement work and power and storage investigations in the Province of Manitoba under the name of the Manitoba Hydrometric Survey.

(4) Carries on all stream measurement work and power and storage investigations in the Province of New Brunswick in co-operation with the New Brunswick Water-Power Commission.

(5) Carries on all stream measurement work and power and storage investigations in the Province of Nova Scotia in co-operation with the Nova Scotia Water-Power Commission.

(6) Co-operates with the Census and Statistics Bureau of the Department of Trade and Commerce in the securing of power census statistics throughout the Dominion.

2. *The Irrigation Branch—*

Carries on all stream measurement work in Alberta and Saskatchewan.

(*b*) The Public Works Department carries out investigations on International and navigable waters.

(*c*) The Department of Trade and Commerce through the Census and Statistics Branch includes in its operations a census of all electrical central stations, including hydro-electric undertakings, co-operating in this work with the Dominion Water-Power Branch.

(*d*) The Department of Marine and Fisheries maintains a Meteorological Service for Canada.

Provincial.—The British Columbia Water Rights Branch has administrative control, and co-operates with the Dominion Water-Power Branch as outlined above.

Alberta, Saskatchewan, and Manitoba are administered and investigated federally by the Dominion Water-Power Branch.

The Ontario Hydro-Electric Commission has a Hydraulic Division which is charged with the investigation of power possibilities and stream measurements in Ontario.

The Quebec Streams Commission carries out all investigations in Quebec.

The New Brunswick Water-Power Commission has administrative control in New Brunswick, and co-operates with the Dominion Water-Power Branch as outlined above.

The Nova Scotia Water-Power Commission has administrative control in Nova Scotia, and co-operates with the Dominion Water-Power Branch as outlined.

Commission on Conservation.—This Commission is advisory in function and status, and, while financed by an annual appropriation from the Federal Parliament, forms no portion of the ordinary Governmental Administration, and possesses no executive or administrative powers. It is authorised solely to study, investigate, and advise. The Commission has formed itself into seven Committees dealing, among other matters, with lands, forests, water and water-power, minerals, and fisheries. It has done much excellent work, and has issued a series of very comprehensive summary reports of the water-powers of Canada as a whole. It has also issued reports dealing with the water-powers of Manitoba, Saskatchewan, and Alberta, and is at present engaged on a comprehensive report of the water-powers of British Columbia. It is also responsible for a number of special reports dealing with power matters of pressing importance, including those concerning international interests and rights.

The Canadian Government, by an Order in Council dated April 25, 1918, has established a body to be known as the "Dominion Power Board." This Board, under the chairmanship of the Minister of the Interior, consists of nine engineer officials selected from the permanent staff of the different

departments of the Dominion Government. Its function is to make a systematic study of the fuel-power situation throughout Canada with a view to encourage the substitution of water-power for fuel-power wherever practicable, and so to co-ordinate the use of water and fuel resources that fuel, and in particular coal, may in future be reserved for purposes such as heating for which it is at present indispensable. It is felt that the rail and water transportation facilities will thereby be relieved of an unnecessary burden, the nation's balance of trade will be favourably affected, since a large part of the coal supply is now imported, fuel resources will be conserved, and the substituted agency, water-power, can never be depleted through use.

Canada is exceptionally fortunate in the extent and distribution of its water-powers. Extending over a belt of several thousand miles in length, from Alaska to Labrador, and over a width of several hundred miles, there is an almost continuous network of lakes and rivers. The table on p. 46 shows how general is the distribution of water-power throughout the Dominion.

The Canadian Conservation Committee estimates that of the 3,730,000 square miles of the Dominion, 2,000,000 miles may be expected to be fairly thickly settled within the next few decades. The remaining area, comprising the North-West Territories, the Northern and Eastern portions of Quebec, and the greater part of the Yukon, is known to have thousands of water-powers, but the capacities of these are so imperfectly known, and they are so remote from any present market, that they are not included in any statistics.

Excluding these districts, it is estimated that 18,803,000 h.p. is available. This amount includes, in the case of Niagara, Fort Frances, and the St. Mary's River at Sault St. Marie, only the development permitted by international treaties, and does not take into account the possibilities of storage for the improvement of present capacities.

The power actually developed up to 1919 amounted to approximately 2,300,000 h.p. About 75 per cent. of this is used for electric light and electric railway and motive-power work, but some 450,000 h.p. is utilised in the manufacture of paper from wood-pulp.

The Department of the Interior in 1917 prepared a sum-

mary of powers as yet undeveloped, but which were capable of rapid and easy development and which aggregate 5,400,000 h.p. In addition to these it was estimated that existing plants could be extended so as to develop an additional 280,000 h.p., so that an aggregate of 7,500,000 h.p. is readily available within range of present markets. At the present accelerated rate of development it appears more than probable that the whole of this energy will be utilised within the next twenty years or so.

On the Winnipeg River almost as much power is available as is now in use at Niagara. In addition to two plants now in operation, and supplying the city of Winnipeg and district, a further seven sites, aggregating 313,500 h.p. (twenty-four-hour power) have been exhaustively investigated, and detailed plans and estimates prepared by Government engineers show that these powers can be developed at from £9 2*s*. to £14 12*s*. per h.p. installed, equivalent to from 19*s*. to 29*s*. per h.p. year.

In Quebec, the Saguenay River alone offers three power sites which can be easily developed to give a total of 1,000,000 h.p. at tide water, with facilities for industrial sites and docks for ocean-going vessels of the largest type, and railroad connection with Quebec. On the Nelson River, Manitoba, there is available at a number of sites, with heads from 17 to 52 feet, some 2,000,000 twenty-four-hour continuous power, or 4,000,000 h.p. for eight months of the year. The river is fed by large lakes, and has very uniform flow, while, owing to the proximity of the Hudson Bay Railway, the power reach is readily accessible.

Shawinigan Falls on the St. Maurice River, about 80 miles east of Montreal, forms an interesting example of a case in which an industrial community has been brought into existence around a water-power. On completion of the storage works now under construction, the river will have a capacity of 204,000 h.p. at the minimum flow period, and this is practically the present capacity of the installed machinery at the Falls. Water is used in the electric generating stations of the Shawinigan Water and Power Co., and is also sold to the Northern Aluminium Co., which generates 33,000 h.p. for use in reduction furnaces, and to the Belgo-Canadian Pulp and Paper Co., which utilises 14,000 h.p. for pulp-machinery. The Canadian Carbide Co. also absorbs 12,000 h.p., so that

besides a miscellaneous local load, industries have been created using 60,000 h.p. at a site where only a few years ago no community existed, and transportation facilities were entirely absent.

Hydro-Electric Power Commission of Ontario.—In initiating a new development at Niagara this Commission has issued specifications that show a notable increase in the size of units to be employed.

This is known as the Chippawa-Queenston development, and is on the Niagara River about 1 mile south of the village of Queenston. The water will be brought from beyond the Falls along a canal 13 miles in length, now under construction, and the total capacity will be 300,000 h.p.

Specifications have been issued for four single runner vertical turbines of 52,500 h.p. each, at 305 feet head and 187·5 r.p.m. Tenders are stated to have been received from three well-known American firms. The generators will be of 45,000 kilovolt-ampères capacity at 80 per cent. power factor, 25 cycles, 12,000 volts.

These turbines will be considerably the largest ever built. The highest powered machines now in operation are believed to be the two 22,500 h.p. units at 168 feet head of the Washington Water-Power Co., Washington, U.S.A., with an overload capacity of nearly 25,000 h.p., and the largest in dimensions the nine 10,800 h.p. units at 30 feet head, of the Cedar Rapids Manufacturing and Power Co., St. Lawrence River, Quebec, Canada. The highest powered vertical turbines are the six 20,000 h.p. units of the Laurentide Company, at Grand Mere, Quebec, Canada.

It may be noted that this Commission initiated, organised, and operates what is believed to be the largest electric transmission system in the world. It has ten systems in operation in Ontario. The largest is that known as the Niagara system, which now supplies 118 municipalities with a total population of nearly 1,000,000, the greatest length of transmission from the source of power being 274 miles and the main line voltage 110,000. Including the other nine systems some 225 municipalities are supplied by 3,000 miles of transmission lines.

The following recent developments in Canada are of interest:

St. Lawrence River.—As is well known, this large navigable river forms, for part of its length, the boundary between Canada

and the United States, and is the subject of international treaties. There are some 700,000 h.p. capable of international development by the two countries. Of this international portion Canada's share is 400,000 h.p., and the Canadian share of the total power capacity of the river is 1,800,000 h.p.

An Order in Council by the Canadian Government, dated September 2, 1918, in reference to this river contains some important announcements on matters of policy.

It makes a proposal "that the two Governments should take immediate steps jointly to prepare and carry out a scheme looking to the most economical and comprehensive development of the waters of the St. Lawrence River in the interests of the people of both countries. Even though the utilisation of only a portion of the whole capacity of the river can be immediately contemplated, yet the endeavour should be to design at the outset a complete scheme into which successive developments might be fitted from time to time as and when occasion might demand. . . .

"It is certain that the subordinate (to navigation) and incidental, but important, use of these international boundary waters for power purposes can never be rendered as efficient and productive through a policy of simply permitting a haphazard series of unrelated private enterprises as through a carefully considered and comprehensive scheme of development carried out under public auspices by the two countries. . . ."

A comprehensive scheme is stated to have already been tentatively submitted in its broad outlines. Surplus power generated and not needed in Canada would be exported to the United States under treaty arrangements, permitting of its return when required on the Canadian side of the international boundary.

A complete census of hydro-electric developments throughout Canada has recently (February, 1919) been completed by the Dominion Water-Power Branch in co-operation with the Dominion Bureau of Statistics, and shows a total of 2,305,310 hydro-electric horse-power now developed. The increase in the last eight years has been 126 per cent. It is of interest to note that this brings up the developed hydraulic horse-power in Canada to 276 per 1,000 of the population. The most recent

figures available for the United States indicate less than 100 h.p.

Respecting capital cost, an analysis of the returns for 70 representative hydro-electric stations with an aggregate capacity of 746,000 h.p., omitting real estate, transmission, and distribution, shows an average total construction cost of $69.11 (£14 4*s*.) per installed turbine horse-power.

The complete census covers the whole field of Central Station industry in Canada and is published in two volumes. Part I., comprising a statistical survey, will be obtainable from the Dominion Bureau of Statistics, Ottawa. Part II. forms a comprehensive directory of all power stations in operation throughout Canada, showing the principal features of each, the locations where blocks of electric energy are for sale and at what price, transportation facilities available, etc. Part II. will be obtainable from the Dominion Water-Power Branch, Ottawa.

The table on p. 46 gives a summary of the results shown by this census as regards hydro-electric power.

State Control.—It has been fortunate that in Canada the water-power rights have mainly remained in the control of the Dominion or Provincial Governments. The Dominion Government controls navigable and floatable streams and their water-powers, and in addition, through the Water-Power Branch of the Department of the Interior, controls all water-power developments in the provinces of Manitoba, Saskatchewan, Alberta, the North-west Territories, and the Yukon, and has now nearly completed a revision of the Dominion Water-Power Law and Regulations designed to bring these in line with the best and most modern practice.

The policy of the Government in respect to the control and administration of water-powers is that the title should be retained by the Crown, that the public should be protected by securing the maximum possible advantageous development of each river, by control of the rates, by reasonable rentals, etc., and that at the same time the inducements should be such as to encourage legitimate enterprise for the development of power resources.

In the province of Ontario the Department of Lands, Forests, and Mines, in conjunction with the Hydro-Electric Commission of Ontario, controls the powers on other than

navigable streams. This Commission is virtually a Government Commission acting in trust for the various municipalities which have combined for the securing of cheap power.

DOMINION WATER-POWER BRANCH AND DOMINION BUREAU OF STATISTICS.

Distribution of developed water-power in Canada by provinces and by use of power, 1918. Figures represent installed turbine horse-power.

	1. *Central Electric Stations.*	2. *Pulp and Paper.*	3. *Other Industries.*	4. *Total.*
	H.P.	*H.P.*	*H.P.*	*H.P.*
Yukon	10,000	—	3,392	13,392
British Columbia ..	221,625	46,450	44,348	312,423
Alberta	32,580	—	300	32,880
Saskatchewan ..	—	—	—	—
Manitoba	64,100	—	12,072	76,172
Ontario	791,163	133,952	59,945	985,060
Quebec	597,601	155,512	89,648	842,761
New Brunswick ..	6,878	2,800	5,191	14,869
Nova Scotia ..	3,354	13,500	9,170	26,024
Prince Edward Island	170	—	1,559	1,729
	1,727,471	352,214	225,625	2,305,310

Column 1 includes only hydro-electric stations which develop electrical power for sale. The stations in this column are designed for extensions of 530,000 h.p., and the Hydro-Electric Power Commission of Ontario has commenced construction of a 300,000 h.p. plant on Niagara River, a total of 830,000 h.p. new construction or extensions in view.

Column 2 includes only the water-power owned by pulp and paper companies. In addition to this total, upwards of 100,000 hydro-electric h.p. is purchased by pulp and paper companies, mainly from the Central Electric Stations included in Column 1. The hydraulic power utilised in the pulp and paper industry of Canada therefore totals 450,000 h.p.

In the province of Quebec the Department of Lands and Forests controls the power in provincial waters. In Nova Scotia many of the water-rights are privately owned outright, from eighteenth-century land grants, but the remaining sites, as in New Brunswick, are under full provincial control.

To its wealth of water-power, the Dominion adds the advantage of a great share in the world's forest and mineral resources. Coal, iron, copper, nickel, gold, silver, cobalt, lead, asbestos, and mica are widely distributed, and the proximity of large hydraulic powers to the mineral deposits will prove a great stimulus to the development of both.

Newfoundland.—No estimate has been made of the water-powers of Newfoundland, but these are known to be of considerable importance. So far about 6,000 h.p. has been developed for general industrial purposes and lighting. About 54,000 h.p. has been developed for use in the pulp and paper mills, and in view of the extent of the forests available for pulp-making, it is probable that the future demand for power for this purpose will be very large.

Smaller Islands of the South Pacific Ocean.—Some few of the islands of the South Pacific Ocean offer possibilities of hydraulic power on a fairly large scale in spite of their comparatively small size. The more promising are New Britain, New Ireland, Guadalcana, Ysabel, Bougainville, Espiritu Santo, Viti Levu, and Vanua Levu. These islands may be expected to produce a total of quite 500,000 h.p. On the other hand, the greater part of such power would be available only after considerable expenditure in retaining walls and dams, and as the islands are subject to outbreaks of earthquake activity, the question of the maintenance of the necessary hydraulic works would be serious.

Present State of Investigation Work.

The present state of affairs as regards investigation throughout the Empire may briefly be summarised as follows:—

United Kingdom.—Active investigations are being made and definite steps taken by the Water-Power Resources Committee of the Board of Trade.

Canada.—Water-power investigation and development is highly organised and carried out on a large scale.

India.—Investigation commenced under Government Departments. A preliminary report already issued. More detailed surveys proceeding and reports expected shortly. Lecture courses in hydro-electric engineering instituted in all chief colleges controlled by Government.

Commonwealth of Australia.—The N.S.W. Government

has made some investigations and issued an interim report. *Victoria* has a Hydro-Electric Department, and is urging on the Government the necessity for further investigation. In *Queensland* no definite information is available.

Tasmania has a State Hydro-Electric Department, and is carrying out investigations of some of the most promising sites. A fair amount of development work has already been carried out.

New Zealand.—Many fine powers. Considerable investigations carried out by Government since 1903, and it is pursuing an active development policy.

Union of South Africa.—Systematic investigation is proposed by the Government, and preliminary cataloguing and classification is in hand.

Ceylon.—The matter is being considered by a Committee appointed by the Government. Some investigation work in progress.

East Africa Protectorate.—The Government has appointed an engineer to make a hydrometric survey. Funds not available for any extended work.

British Guiana.—A preliminary investigation of a number of sites has been made. Stream gauging operations are intended, and a further and more extended examination of the more promising sites is probable.

Egypt.—The subject is under consideration, particularly as regards the possibility of utilising the power rendered available by the construction of the Aswan Dam.

Honduras, New Guinea, and *Newfoundland* are portions of the Empire known to have very large water-power resources, but in which little investigation has been made, and in which no definite steps to that end are being taken.

Gold Coast, Pacific Islands, and Rhodesia are known to have considerable water-power, but even less information available, and no steps being taken.

Malay States, Nigeria, and West Africa.*—Practically no information available and no steps being taken.

* Since the publication of the final report of the Water-Power Committee, a report dated May, 1921, on Electric Light and Power Supplies for Malaya, by Mr. F. Bolton, M.Inst.C.E., has become available. This is a record of investigations carried out for the Crown Agents for the Colonies since 1919, and deals, among other things, with the hydro-electric possibilities of Malaya.

It will be seen that in Great Britain, India, Canada, New Zealand, Tasmania, and some portion of Australia, more or less adequate steps are being taken by the various Governments, and that definite preliminary steps have been taken in the Union of South Africa, in British East Africa, in Ceylon, in British Guiana, and in Egypt. In the remaining countries of the Empire nothing definite is being done, or appears to be projected, although the potential water-power in many of these is known to be very large indeed; while where investigation work has been initiated, with the exception of Great Britain, Canada, New Zealand, and possibly India, the scope of the work does not appear to be in any way commensurate with the importance of the subject.

Taking the Empire as a whole, no attempt is being made to ascertain the total resources, to secure any uniformity in methods of investigation and recording of data, to encourage such investigations as are being made, or to collect the information as it becomes available at a central bureau. At present not even an approximately complete inventory exists, much less the practical and commercial information that would assist development of this important national resource.

Conclusions.

The main conclusions to be drawn from the evidence available to the Committee are:—

(1) That the potential water-power of the Empire amounts in the aggregate to at least 50 to 70 million horse-power.

(2) That much of this is capable of immediate economic development.

(3) That except in Canada and New Zealand, and to a less extent in India, New South Wales, and Tasmania, no systematic attempt has as yet been made by any Government Department to ascertain the true possibilities of the hydraulic resources of its territories, or to collect the relevant data.

(4) That the development of the Empire's natural resources is inseparably connected with that of its water-powers.

(5) That the development of such enormous possibilities should not be left to chance, but should be carried out under the guidance of some competent authority.

In view of these conclusions the Committee would submit the following recommendations:—

Recommendations.

1. That the British Government bring before the notice of the Indian Government, of the various Dominion Governments, and of the Governing Bodies of the Crown Colonies, the necessity for a close systematic investigation of all reasonably promising water-powers, and of their economic possibilities.

2. That the British Government take steps to ascertain whether the Governments concerned are prepared to undertake this work.

3. That where such an enquiry is beyond the powers of any governing body, the British or Imperial Government place the work under the direct control of an "Imperial Water-Power Board" or "Conservation Commission."

4. That the Government take steps to initiate the formation of such an "Imperial Water-Power Board" or "Imperial Conservation Commission," to include a representative from each of the Dominions and Dependencies.

5. That this Board act in an advisory capacity.

It should decide on the sequence of such investigation work as comes under its purview.

It is suggested that all schemes for the development of which local resources are inadequate, should be submitted to the Board by the Governments concerned, and that the Board should make recommendations on which the Imperial Government might take action.

Such a Board would be able to take a broad and comprehensive view of the advantages to the Empire as a whole, attending the development of any given scheme, and would be able to form a reasonable decision as to the relative advantages of such different schemes as might be brought forward from different parts of the Empire.

6. That since it is unlikely that private capital will be available for many years for hydraulic development on any large scale, powers should be obtained to enable the State to assist or to undertake such development if thought advisable.

It is suggested that much might be done to attract private capital, if the State, after careful investigation, were to guarantee a suitable minimum interest on the necessary capital, sharing at the same time in any profits beyond the amount necessary to provide that interest. By this method of assistance private enterprise would be untrammelled, and the management of the concerns so assisted would remain in private hands.

7. In view of the great developments in hydro-electric engineering which are inevitable throughout the Empire during the coming decade, it would appear to be of the greatest importance that the engineers of Great Britain should be prepared to take a commensurate part in such development. In the past large scale hydro-electric engineering has been confined very largely to Canadian, American, or Continental engineers and corporations, and unless some definite and early endeavour is made in this country to make up the leeway, it is probable that the bulk of the Empire's future water-power will be developed outside the country.

While there is some indication that strong financial and manufacturing interests are now considering such developments, the Committee would draw attention to the lack of facilities in our Universities for giving the necessary specialised scientific training to the young engineer wishing to enter this field of engineering.

The Committee would emphasise the fact that an adequate supply of suitably trained engineers is essential to the attainment and maintenance of such a position in the hydro-electric world as is commensurate with the importance and capacity of the British engineering industry. It attaches great importance to the early provision of training facilities of such a standard as those, for example, at Cornell University, in one or more of the engineering schools in this country, and would recommend that its views in this matter be brought to the notice of the Minister of Education and of the Secretary for Scotland.

8. That the Government be advised to take steps to convene an Imperial Water-Power Conference in London in the near future. This Conference would include a member from each of the Dominions and Dependencies of the Empire.

Proposed Imperial Water-Power Board.

In view of the importance which the Committee attach to the formation of this Board, they would desire to make a few suggestions as to the principal objects that it should endeavour to carry out.

(*a*) It should get into touch with every Dominion and Dependency with a view to ensuring comprehensive investigation on a uniform method and system, and to secure the initiation of investigations where these are not already in hand. The Water-Power Resources Committee of the Board of Trade are making a thorough study of methods of securing and recording water-power data, and it would have many advantages if the methods suggested by that Committee or some modification of these could be adopted as far as possible throughout the Empire. Uniformity in this matter would add greatly to the commercial value of the data secured.

(*b*) The Board should endeavour to make co-operative arrangements for carrying out investigations in such Dependencies as are not in a position to undertake them unaided, on some such basis as is arranged under similar circumstances by the United States.

(*c*) Arrangements should be made with all Overseas authorities for complete copies of all data secured and reports issued to be on file at an Imperial headquarters in London for the information of promoters or companies seeking for water-power to develop, and for incorporation as desired in Imperial publications on water resources.

(*d*) From these the Board should compile and publish an Annual Report, and detailed annual records of investigations throughout the Empire in a uniform form, as is done by the United States in its "Water Supply Papers," and by the Dominion of Canada in its "Water Resources Papers." Such a course could not fail to stimulate the investment of capital in the development of natural resources.

(*e*) The Board should keep a complete and up-to-date file at its headquarters in London of all information obtained on water-power resources in all parts of the Empire, in such a form that the information available as to any river or district could be immediately produced and summarised. It should,

in fact, be a Central Clearing House of information on this subject for the whole Empire.

(*f*) The information on record should include such particulars as are known of allied natural resources available for manufacturing purposes, transportation facilities, etc. It is not suggested that the Board should investigate natural resources other than water-power, but that it should collate brief particulars of such resources locally available with references as to where fuller information can be obtained.

(*g*) It should be possible for any capitalist or company needing cheap power in large quantities to ascertain at the offices of the Board, from information immediately available, all the water-powers in certain districts, with the state of investigation for each, in such a form that it could be decided which locality and which power appeared sufficiently promising to justify further detailed investigation. If a definite enquiry were received by mail it should be possible to send promptly a digest of the information available.

(*h*) For such purposes, whenever possible, investigations of rivers should be carried out with sufficient thoroughness to allow of reasonably close estimates of costs being obtained. These estimates should be made by the engineers of the Government concerned.

(*i*) To carry out these functions the Board would require a permanent staff consisting of administrative officers, technical experts, and clerical assistants. A permanent staff dealing with the resources of all parts of the Empire would be necessary to secure continuity of policy and absolute impartiality.

The Committee feel that the creation of such a Central Board to assist and record all available data would give an impetus to the investigation of water-power resources, and that the greater uniformity of methods of investigation and recording to be secured by such a Board would add greatly to the commercial value of the information.

While the Committee have been able to deal with the enquiries submitted to them and with the somewhat meagre information so far available, they feel that, forming as they do a body without any permanent staff and without financial resources, it will be quite beyond their powers to deal efficiently with the results of the many Empire investigations recently

initiated when these become available. Under the circumstances they have come to the conclusion that little further benefit would result from a continuation of their activities, and have decided to conclude these with the presentation of these reports.

The personnel of the Committee is as follows:

Mr. John Ashford, M.Inst.C.E.
Sir John Benton, K.C.I.E.
Sir Dugald Clerk, K.B.E., F.R.S. (*Chairman*).
Professor E. David, C.M.G., F.R.S.
Professor A. H. Gibson, D.Sc., M.Inst.C.E. (*Hon. Secretary*).
Mr. W. Vaux Graham, M.Inst.C.E.
Mr. H. E. M. Kensit, M.Inst.E.E.
Mr. A. E. Kitson.
The Right Hon. Lord Lamington, G.C.M.G., G.C.I.E.
Sir Murdoch Macdonald, K.C.M.G., M.Inst.C.E.
Sir Douglas Mawson, D.Sc.
Professor J. C. McLennan, Ph.D., F.R.S.
Mr. H. R. Mill, D.Sc., LL.D.
Mr. A. Newlands, M.Inst.C.E.
Mr. Evan Parry, B.Sc., M.Inst.C.E., M.Inst.E.E.
Sir John Snell, M.Inst.C.E.
Mr. A. A. Campbell Swinton, F.R.S.
The Right Hon. Lord Sydenham, G.C.S.I., G.C.M.G., F.R.S.
Sir Joseph J. Thomson, O.M., Pres.R.S. (*Chairman of the Conjoint Board*).
Professor W. C. Unwin, F.R.S.
Professor W. W. Watts, F.R.S. (*Hon. Sec. of the Conjoint Board*).

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